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# A Multibeam, Spherical-Reflector Satellite Antenna for the 20- and 30-GHz Bands

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*A multibeam antenna for satellite communication affords reuse of frequency allocations and flexibility in traffic routing. A multibeam satellite antenna is described that employs a spheroidal reflector in a compact periscope design. The aperture is 1.5 meters in diameter radiating six beams in the 20- and 30-GHz satellite frequency bands. Electrical measurements indicate that this antenna is suitable for multibeam satellite use.*

## I. INTRODUCTION

A proposed domestic satellite system for the 20- and 30-GHz radio bands includes a multiheam satellite antenna.[1] The use of separate radiating heams to service specific densely populated urban areas is desirahle since it permits reuse of the frequency bands and flexibility in traffic routing.

A multibeam satellite antenna that operates simultaneously in the 20- and 30-GHz hands has been constructed and evaluated electrically. Tbe antenna is a compact periscope design[2] employing a spherical reflector 60 inches in diameter, a plane reflector, and a cluster of six feed borns. Figure 1 shows two views of the antenna system. A spherical rather than a paraholic reflector was employed to permit off-axis beam pointing with less degradation in performance than a paraboloid. The primary feature of this antenna design is the use of multiple feeds to produce separate radiation beams. The feed location format was chosen to conform with earth-station locations at approximately New York City, Denver, Atlanta, Los Angeles, Honolulu, and Puerto Rico. These locations are representative of the maximum beam-pointing requirement for domestic satellite service and tbe minimum beam-pointing constraint owing to physical feed separation. The synchronous orhiting satellite was assumed to be located at 100 degrees west longitude. The antenna system boresight axis that corresponds to the axis of symmetry of the spherical reflector is designed to intersect the earth at 38 degrees north latitude and 100 degrees west longitude, near the geo-

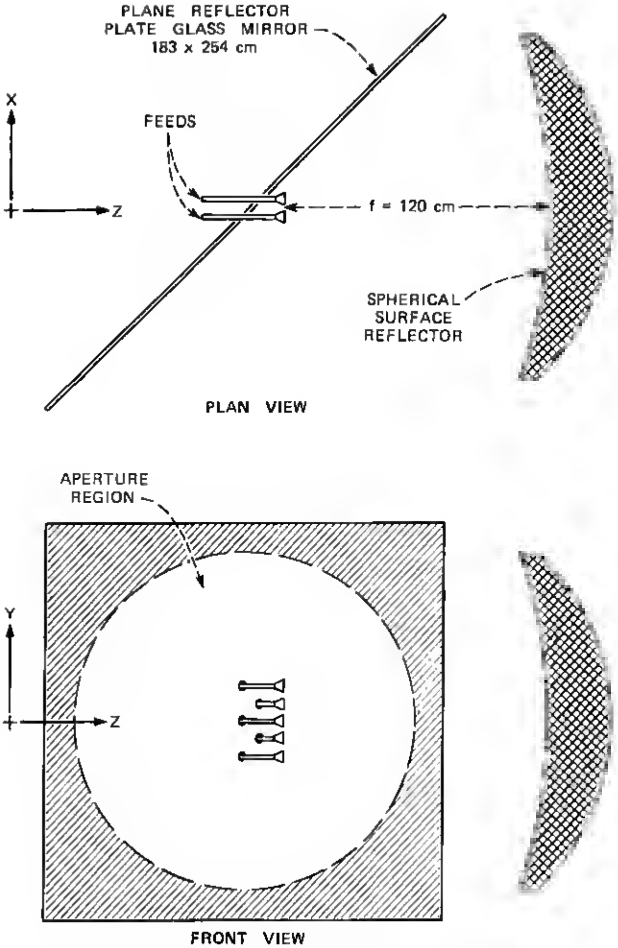


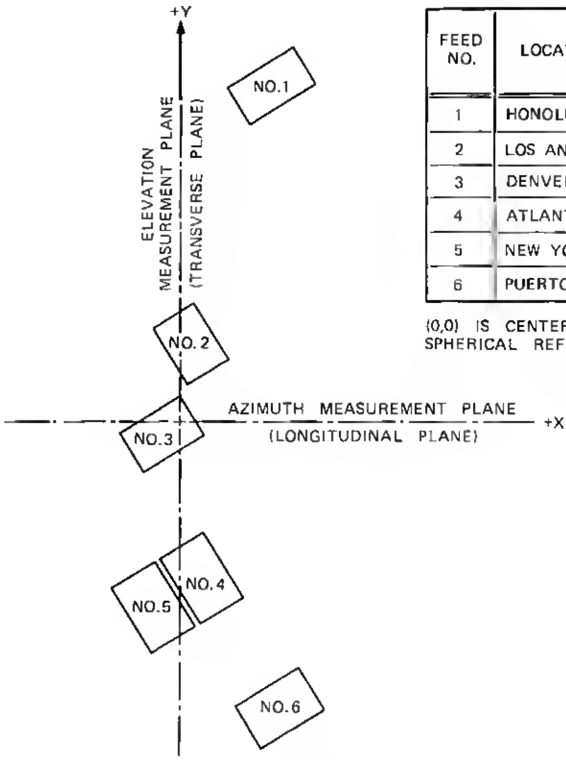

Fig. 1—Multibeam antenna.

graphic center of the contiguous United States. With these geographical constraints, the maximum beam-pointing angle off boresight is about ±6.5 degrees in the east-west direction to include Honolulu and Puerto Rico.

Parameters of chief interest in the electrical evaluation of this antenna system are isolation between beams, absolute pointing accuracy of beams, coupling between feeds, and performance degradation because of feed-cluster blockage. Although these parameters may be evaluated analytically, the last one is especially difficult to analyze. For this reason and to demonstrate the others, a laboratory model was constructed and measurements were made.

## II. CONSTRUCTION

The laboratory model was constructed to evaluate the electrical performance of the multibeam design and is not structurally compatible with space vehicle requirements. The physical size of the aperture, dictated mainly by measurement facilities, may be considered as a scale model for a larger aperture. The 150-cm-diameter spherical reflector was fabricated at the Crawford Hill laboratory of urethane foam and epoxy materials and used a deep spun-aluminum paraboloid for basic structural integrity. The surface was machined to an rms accuracy of 0.05 mm using a 244-cm radial arm end mill. The plane reflector is a 0.64-cm-thick plate glass mirror employing the metalized side as a reflecting surface. The mirror is suspended with its plane vertical to minimize warpage resulting from gravity. Six holes are bored through the plate glass to admit the feeds with a minimum loss of surface area. The feed location format shown by Fig. 2 is on a plane normal to the axis of the spheroidal reflector.




| FEED NO. | LOCATION | COORDINATES (CENTIMETERS) | |
|---|---|---|---|
| | | X | Y |
| 1 | HONOLULU | +4.02 | +14.9 |
| 2 | LOS ANGELES | +0.43 | +3.46 |
| 3 | DENVER | −0.79 | −0.66 |
| 4 | ATLANTA | +1.02 | −7.00 |
| 5 | NEW YORK | −1.22 | −8.36 |
| 6 | PUERTO RICO | +4.58 | −12.70 |

(0,0) IS CENTER OF SPHERICAL REFLECTOR

Fig. 2—Feed format.

The feed horns were designed for dual-frequency operation with linear polarization. The polarization for the 20- and 30-GHz bands are orthogonal. Figure 3 shows details of the feed horn employing thin conductive fins that redefine the electrical aperture for the 30-GHz band. Since the 20-GHz polarization is normal to the fins, the feed-horn walls define the aperture for this band. By using the fins to selectively control the feed aperture size, the radiation patterns at both 20 and 30 GHz are more nearly the same, resulting in optimum illumination for the spheroidal reflector at both frequencies. Figures 4 and 5 show feed radiation patterns at measurement frequencies of 19 and 30.2 GHz.

The axis of each feed was aligned parallel to the axis of the spheroidal reflector aperture and the feed-phase centers were arranged in a single plane located 120 cm from the center of the spheroidal reflector. Measurements on positioning of a single movable feed showed that there is no significant difference in radiation characteristics of the antenna system for the off-axis heam-pointing directions under consideration with the feed axis oriented (*i*) along a radial direction from the center of curvature of the spheroidal surface, (*ii*) parallel to the axis, or (*iii*) directed toward the center of the spheroidal reflector to balance the amplitude distribution. Parallel mounting of the feed axes greatly simplifies the feed-line structure. It was also found that arranging the phase centers in a plane rather than in the optimum spheroidal focal surface produces an error in focal length of less than $\lambda/2$ at 30 GHz with little effect on the gain or radiation characteristics of the system.

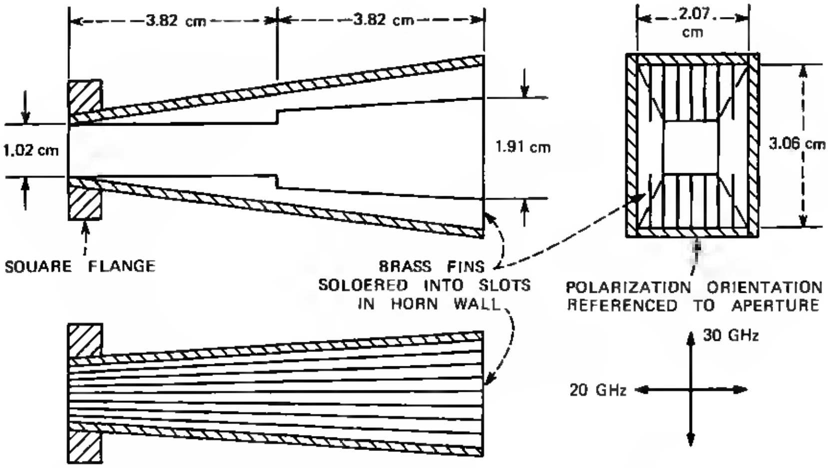



Fig. 3—Linearly polarized feed horn, dual frequency (17.7–20.2 GHz and 27.5–30.0 GHz).

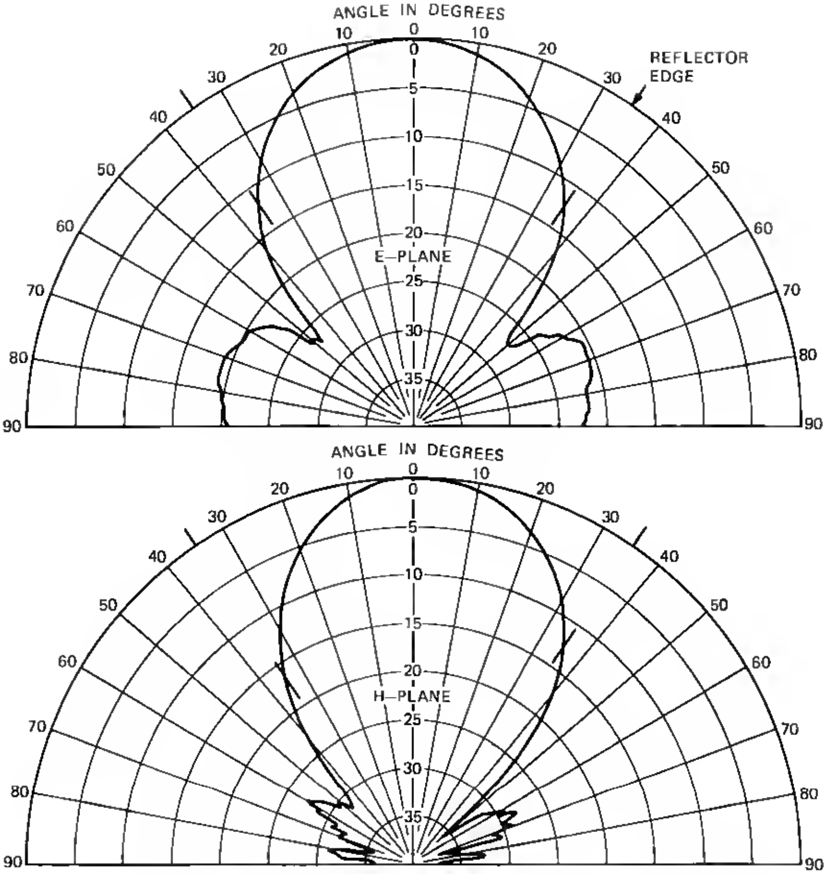



Fig. 4—Radiation patterns of the finned feed horn at 19.0 GHz.

The polarization orientations of the feeds were mandated by the physical constraint of the feeds in New York City (feed 5) and Atlanta (feed 4) feeds. These two feeds were parallel-polarized and arranged at a skew angle with respect to the measuring plane to achieve a minimum physical spacing. The remaining feeds were cross-polarized with their adjacent neighbors for minimum electrical coupling. The feed locations shown in Fig. 2 were necessary to achieve the desired beam-pointing angles for the various earth-station locations.

## III. MEASUREMENTS

Electrical evaluation of the multibeam antenna was conducted at the Holmdel radio range. A variation was found of incident field over the measurement aperture of no greater than ±0.75 dB for either 19 or 30 GHz, the measurement frequencies used.

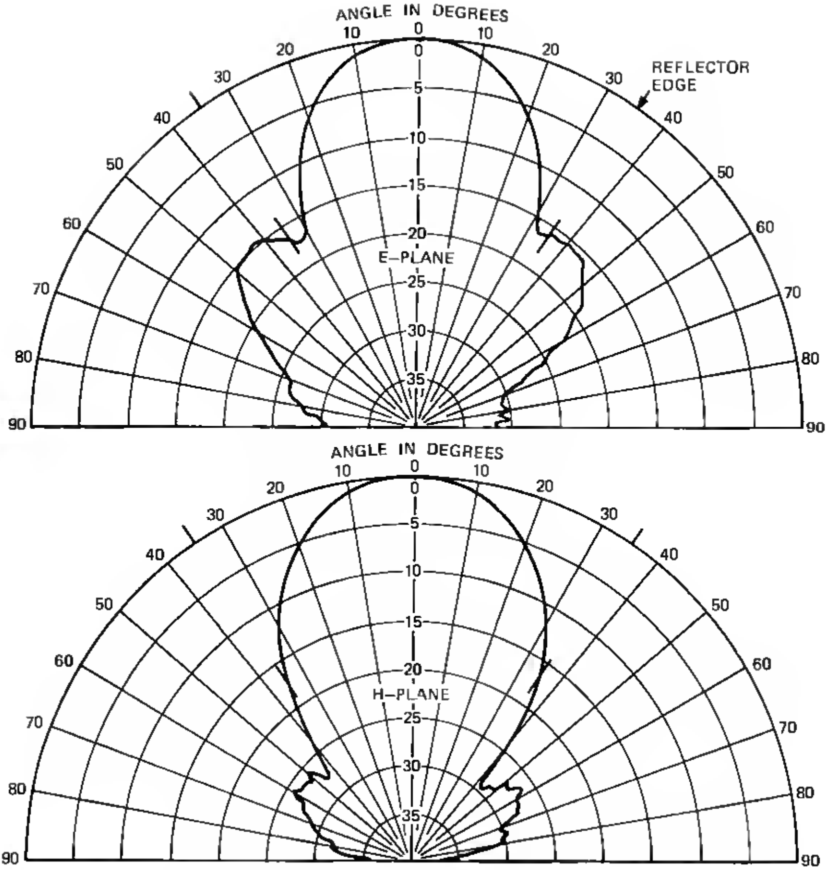



Fig. 5—Radiation patterns of the finned feed horn at 30.0 GHz.

### 3.1 Beam pointing

Beam-pointing accuracy is important in the design of a satellite system. Measurement of pointing accuracy for each of the six beams was accomplished by first mechanically measuring the location of each feed phase center relative to the axis of the spheroidal reflector (boresight axis) and in the $X$-$Y$ plane (Fig. 1). Alignment of the boresight axis with the radio source was done by optical sighting. All measurements of beam pointing were made using synchro-type readouts with an accuracy of 0.05 degree. Angular measurements are in essentially an orthogonal coordinate system for the elevation-over-azimuth mount.

Table I shows all the measured beam-pointing data, together with computed data based on feed location, and the pointing errors. The feeds are numbered as in Fig. 2. Since the half-power beamwidth of

Table I — Measured and computed beam-pointing errors

| Feed No. | Freq. (GHz) | Measured $\theta_x$ (Degrees) | Computed $\theta_x$ (Degrees) | Pointing Error (Degrees) | Measured $\theta_y$ (Degrees) | Computed $\theta_y$ (Degrees) | Pointing Error (Degrees) |
|---|---|---|---|---|---|---|---|
| 1 Hon. | 19.0 | −1.95 | −1.87 | −0.08 | +6.82 | +6.90 | −0.08 |
| | 30.2 | −1.71 | | +0.16 | +7.28 | | +0.38 |
| 2 L.A. | 19.0 | −0.35 | −0.20 | −0.15 | +1.50 | +1.61 | −0.11 |
| | 30.2 | −0.15 | | +0.05 | +1.75 | | +0.14 |
| 3 Den. | 19.0 | +0.20 | +0.37 | −0.17 | −0.45 | −0.31 | −0.14 |
| | 30.2 | +0.45 | | +0.08 | −0.30 | | +0.01 |
| 4 Atl. | 19.0 | −0.58 | −0.48 | −0.10 | −3.44 | −3.25 | −0.19 |
| | 30.2 | −0.40 | | +0.08 | −3.40 | | −0.15 |
| 5 N.Y. | 19.0 | +0.35 | +0.57 | −0.22 | −4.17 | −3.90 | −0.27 |
| | 30.2 | +0.56 | | −0.01 | −4.08 | | −0.18 |
| 6 P.R. | 19.0 | −2.19 | −2.12 | −0.07 | −6.14 | −5.89 | −0.25 |
| | 30.2 | −2.05 | | +0.07 | −6.15 | | −0.26 |

each beam at both 19 and 30 GHz is about 0.65 degree, the maximum error encountered in these measurements was about one-half beamwidth. Considering the readout accuracy, mechanical errors in the structure, and boresight errors, these results are remarkably consistent; the antenna beams point in the intended directions.

### 3.2 Beam coupling

Beam coupling is a measure of the signal level in one specified beam when another beam is aimed toward tbe source. It is also a measure of the interference between any two particular ground stations. The radiation characteristics of each beam for specific off-axis angles specify the coupling. Measured coupling for all combinations of beams except the New York City-Atlanta combination was found to be less than −35 dB. In that case, the angular separation in the beams is only 1.2 degrees and the coupling is approximately −20 dB. The data were measured at specific incremental frequencies over the 2500-MHz band at both 20 and 30 GHz.

The beam coupling is strongly dependent on exact pointing directions and can be greatly improved by slight misalignment of the main beams. It may, therefore, be an engineering expedience to suffer a slight degradation in gain by beam misalignment to improve the isolation.

### 3.3 Radiation patterns

Studies of the radiation characteristics of tbis antenna with a single horn feed were made prior to installation of the six-feed cluster. These

measurements were made to determine the effects of illumination on beams pointed off-axis. Figure 6 gives measured values of relative gain and first side lobes with off-axis pointing. The asymmetric illumination with off-axis pointing produces an effect similar to coma aberration in which the first side lobe levels become increasingly unbalanced. The side lobe nearest the axis of the antenna system is always the higher in level, as expected.

The gain degradation for maximum off-axis pointing is a modest 1 dB at 19 GHz. At 30 GHz, the extrapolated degradation is approximately 2 dB. Representative measured far-field radiation patterns for the single feed are shown by Figs. 7 and 8. These are principal plane measurements, that is, patterns taken with a single feed whose polarization orientation is parallel with the measurement plane; they show the typical far-side-lobe behavior of this type of antenna.

Figures 9 and 10 are far-field radiation patterns at 19.0 GHz for feeds 1 and 3, when all other feeds are in place and terminated. These are representative of the maximum and minimum off-axis pointing. Figures 11 and 12 are for the same feeds at 30.2 GHz. These patterns illustrate the off-axis asymmetric radiation characteristics; the effect

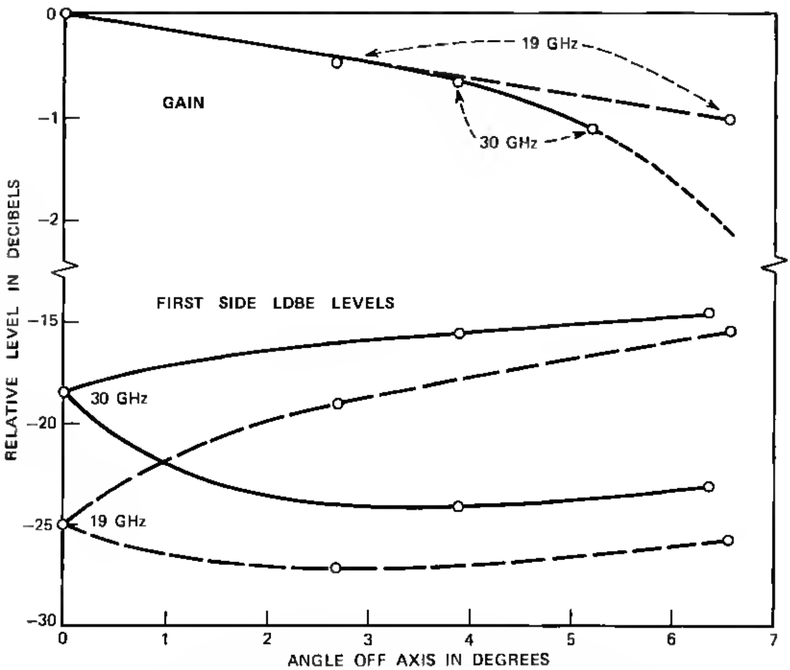



Fig. 6—Single-feed measurements of off-axis performance.

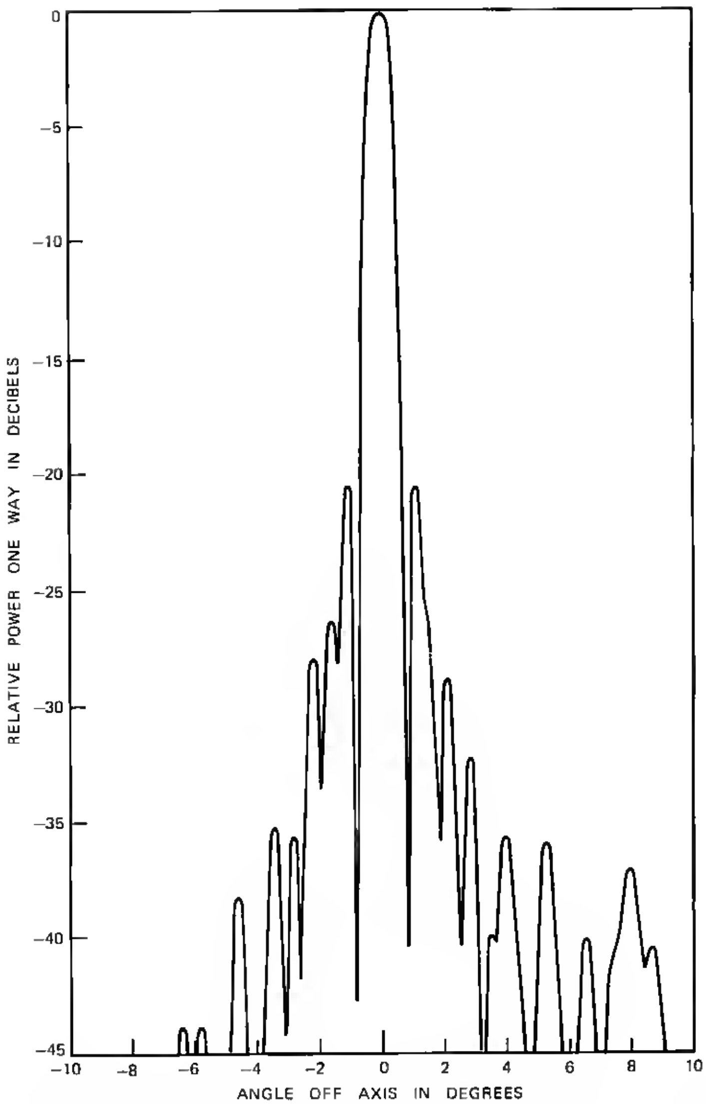



Fig. 7—Far-field radiation pattern at 30.0 GHz, single-feed centered in longitudinal plane (azimuth).

is more pronounced at the higher frequency where the relative aperture phase errors are greater. These patterns also indicate that the small blockage from the feed cluster causes negligible distortion of the beams.

The half-power beamwidths are essentially equal for both 19 and 30 GHz; this is because the feed illumination taper is somewhat more

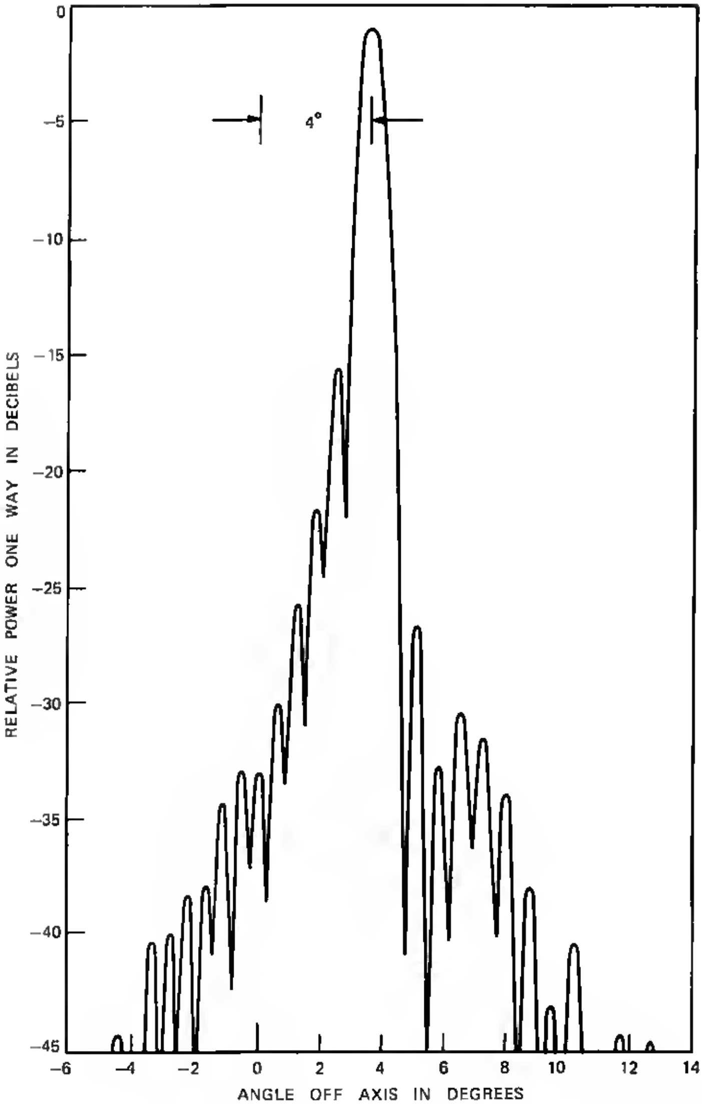



Fig. 8—Far-field radiation pattern at 30.0 GHz, single-feed offset in longitudinal plane.

severe at 30 GHz and because the reflector surface errors cause more degradation at the higher frequency.

### *3.4 Gain*

Absolute gain measurements shown in Fig. 13 corroborate the pattern measurements; the gain falls off faster with off-axis pointing

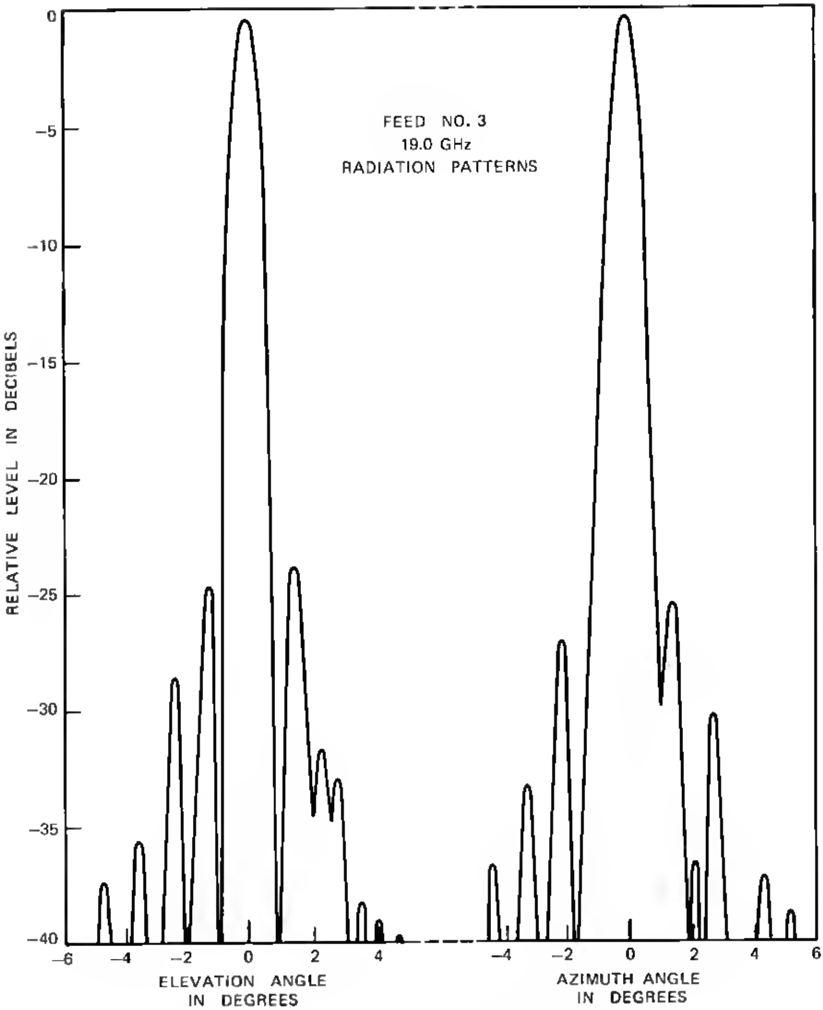



Fig. 9—Feed 3, 19.0-GHz radiation patterns.

at 30 GHz than at 19 GHz. The plotted values in Fig. 13 show the relative gain measured for each feed. These data are consistent with single feed measurements where off-axis gain degradation was somewhat more at 30 GHz than at 19 GHz. The aperture efficiency for the feed nearest center, No. 3, is 54 percent at 19.0 GHz and 35.5 percent at 30.2 GHz.

### 3.5 Reflection coefficient

The magnitude of the reflection coefficient over each frequency band was measured at each feed port. The maximum value is −18 dB typi-

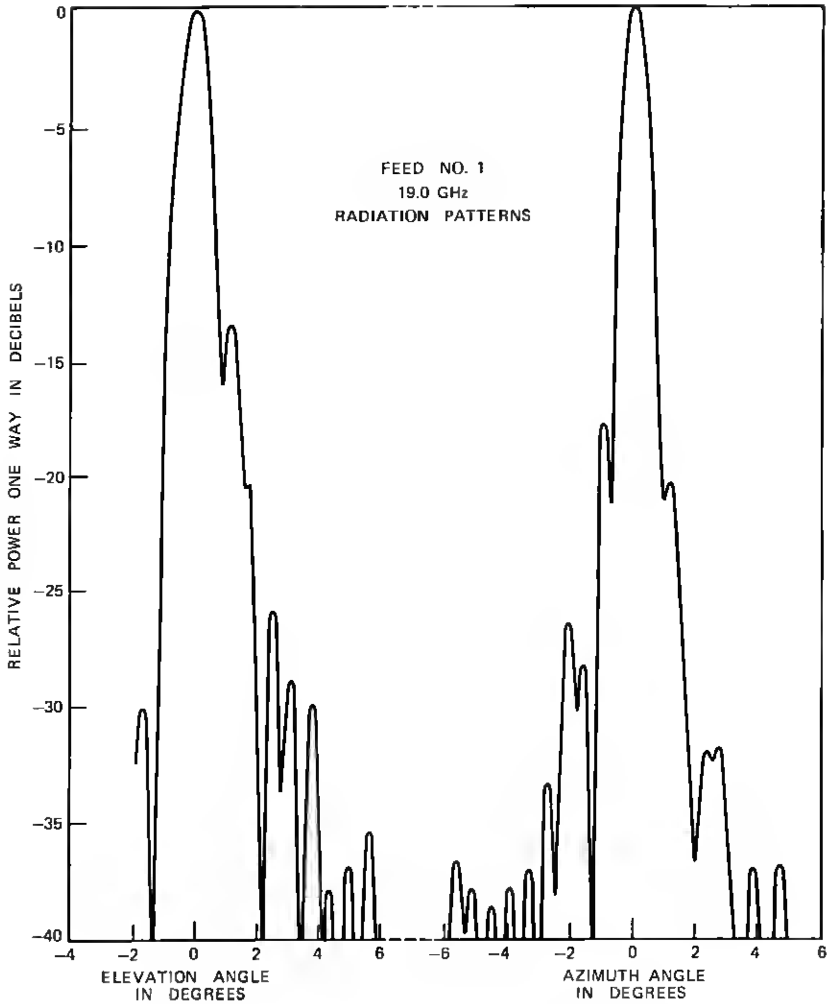



Fig. 10—Feed 1, 19.0-GHz radiation patterns.

cally for all ports over the band 18.3 to 20.3 GHz. Figure 14 shows a typical reflection coefficient measurement for the 19-GHz band. The periodicity in the reflection coefficient indicates a mismatch at the feed horn to be approximately the same magnitude as the echo from the spheroidal reflector. The same type of periodicity is observed in the reflection coefficient measurement over the 27.5- to 30.2-GHz band as shown in Fig. 15. In this case, however, the reflection coefficient is much worse with a maximum value of −12 dB toward the low-frequency end of this band.

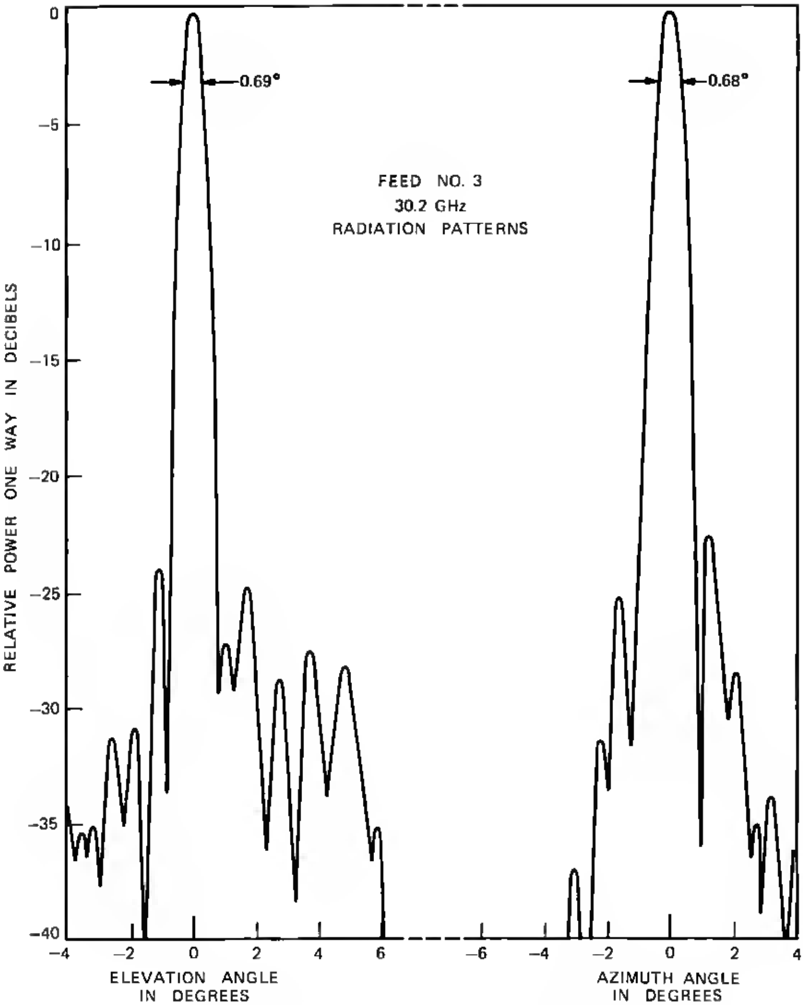



Fig. 11—Feed 3, 30.2-GHz radiation patterns.

### *3.6 Coupling between ports*

Direct coupling between feed ports results from two causes: (*i*) reflections from the spherical reflector into other feed horns and (*ii*) direct side-to-side radiation of the feed horns. Direct measurement of all 15 feed-coupling combinations (assuming reciprocity) was made on a scanned frequency basis. Three of the feeds are essentially cross-polarized with respect to the other three, and those nine cross couplings that involved the cross-polarized condition were found to have coupling levels less than −40 dB. Of the remaining six combinations of

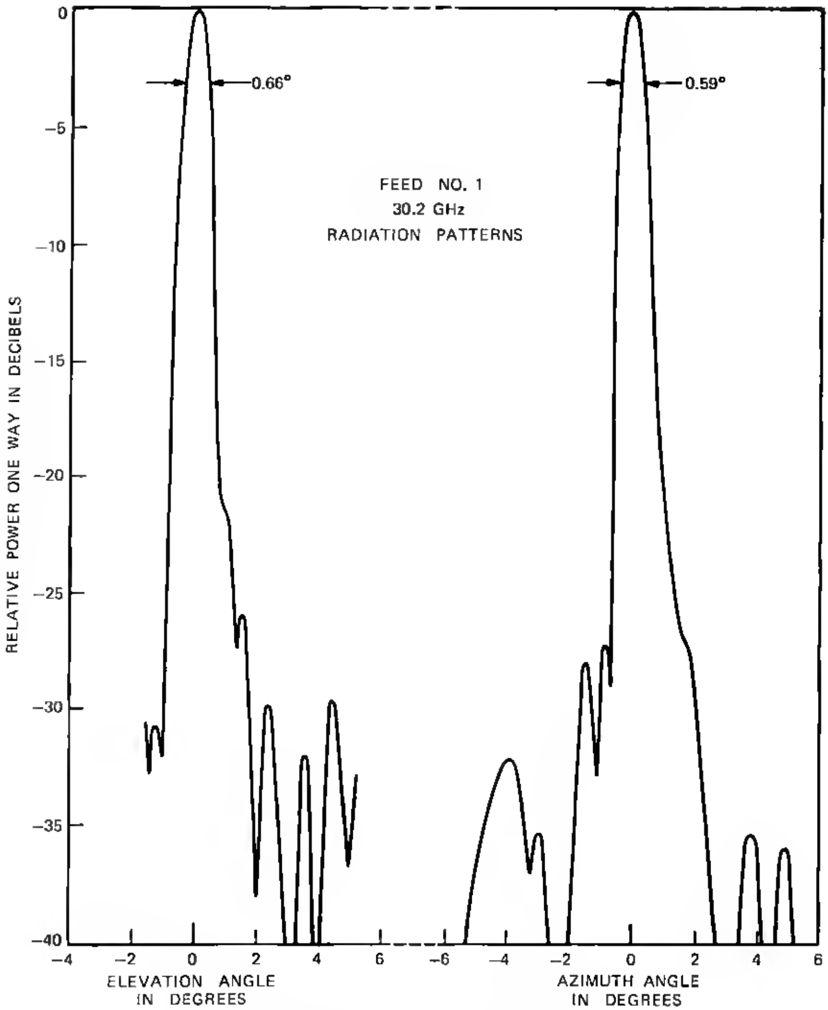
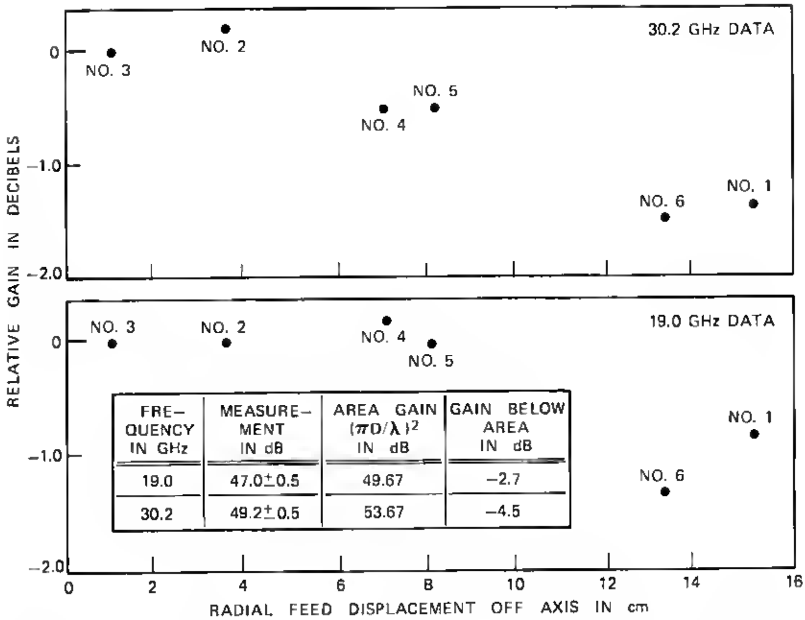



Fig. 12—Feed 1, 30.2-GHz radiation patterns.

coupling for each frequency band, the worst case is for the adjacent feeds 4 and 5 (New York-Atlanta), which show values of −24 dB at 20 GHz and −26 dB in the 30-GHz band. All others show coupling less than −28 dB, consistent with reflection coupling from the spherical surface alone. All unused ports were terminated during these measurements.

## IV. CONCLUSIONS

Measurements on a compact spherical periscope antenna indicate that this design is suitable as a multibeam satellite antenna for the




| FREQUENCY IN GHz | MEASUREMENT IN dB | AREA GAIN $(\pi D/\lambda)^2$ IN dB | GAIN BELOW AREA IN dB |
|---|---|---|---|
| 19.0 | 47.0±0.5 | 49.67 | −2.7 |
| 30.2 | 49.2±0.5 | 53.67 | −4.5 |

Fig. 13—Absolute gain measured at feed port 3 by standard gain horn techniques.

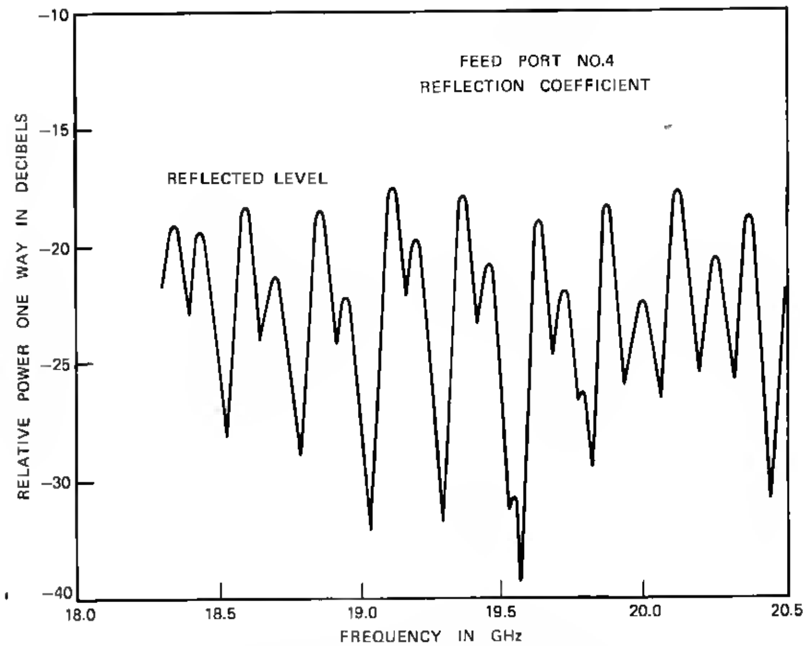



Fig. 14—Feed port 4, reflection coefficient.

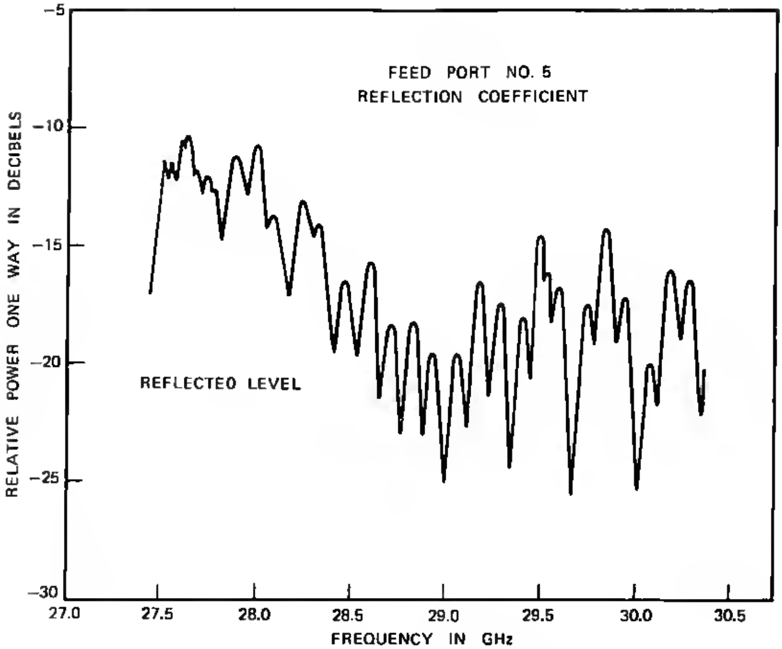



Fig. 15—Feed port 5, reflection coefficient.

20- and 30-GHz bands. While the aperture diameter, 150 cm, may be somewhat small for practical use, most measured results are equally applicable to larger aperture designs.

The only feature of the design not amenable to analysis is the blockage and scattering by the cluster of feeds. However, the measurements reported here indicate that this effect is of little consequence in the intended application. It is also clear that some limitations of the embodiment discussed here are inherent in the feed design. Minimum physical separation between feeds limits the minimum angular beam separation to about 1.2 degrees in this particular antenna, isolation between these beams being of the order of −20 dB.

## V. ACKNOWLEDGMENTS

I would like to thank A. B. Crawford for inspiring the antenna design, T. S. Chu for designing the feed, and J. H. Hammond for assisting in the many range measurements.

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